Comparison of Collisional Drift-Wave Simulation with CSDX Experimental Results

P. Vaezi[1], C. Holland[1], E. Bass[1], G. R. Tynan[1], S. C. Thakur[1], C. Brandt[1], B. Dudson[2], B. Friedman[3], T. A. Carter[3]
UCSD[1], York University[2], UCLA[3]

Center for Energy Research

Motivation and Setup

- Study of plasma turbulence in a simpler geometry than Tokomaks.
- Experimental studies has been done on UCSD Controlled Shear De-Correlation Experiment (CSDX) [1] (See Fig. 1).
- BOUT++ introduced a object-oriented framework for writing fluid/plasma simulations in curvilinear geometry [2].
- First simulation attempts has been done by implementation of 2D turbulence model in BOUT++.
- In this poster, we present initial studies comparing original 2D model as implemented in BOUT++ against analytic theory and experimental data for various applied magnetic fields.

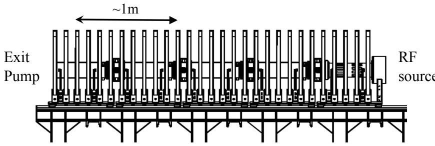


Figure (1): Schematic of CSDX linear device used in the experiments [1].

Comparison with Theory

- In the first step, we verify an implementation of 2D Hasegawa-Wakatani turbulence model in BOUT++ against theory,

$$\frac{\partial \tilde{n}}{\partial t} + \frac{V^*(r)}{r}\frac{\partial \tilde{\phi}}{\partial \theta} + \frac{V_{te}^2}{\nu_{ei}} k_z^2 \left(\tilde{n} - \tilde{\phi}\right) = 0; V^*(r) = \rho_s c_s \frac{r}{L_n^2}$$

$$\frac{\partial \tilde{\Omega}}{\partial t} + \frac{V_{te}^2}{\nu_{ei}} k_z^2 \left(\tilde{n} - \tilde{\phi}\right) = \mu_{ii} \nabla_\perp^2 \tilde{\Omega}; \tilde{\Omega} = \rho_s^2 \nabla_\perp^2 \tilde{\phi}$$

Assumptions
- Gaussian n_0
- T_e=4eV ; T_i=0
- Constant μ_{ii}

- Analytical linear dispersion relation reads as,

$$-ik_\perp^2 \rho_s^2 \omega^2 + \left[\omega_\parallel\left(1 + k_\perp^2 \rho_s^2\right) + \mu k_\perp^4 \rho_s^4\right]\omega - \omega_\parallel\left(\omega^* - i\mu k_\perp^4 \rho_s^4\right) = 0$$

- Comparison of growth rate and linear frequency for different azimuthally mode numbers shown in Fig 2.a & b. Simulation results have acceptable accuracy with theory however, there is problem of eigenmodes not matching up exactly to the Bessel function (Fig 2.c).
- Limit cycle case has also been qualitatively compared to the results of ref [3] and acceptable behavior has been obtained in BOUT simulations (Fig. 3). Note that time traces use different normalization.

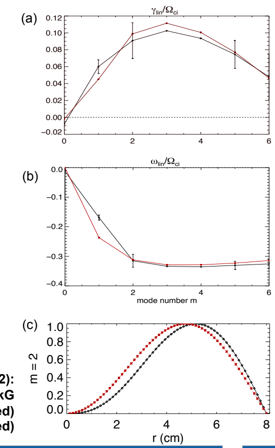


Figure (2):
a. Modenumber growth rate of simulation (black) and comparison with theory [3] (red) at B=1kG
b. Modenumber linear frequency from simulation (black) and comparison with theory [3] (red)
c. Radial potential distribution comparison of m=2 (black) with analytical Bessel function from theory (red)

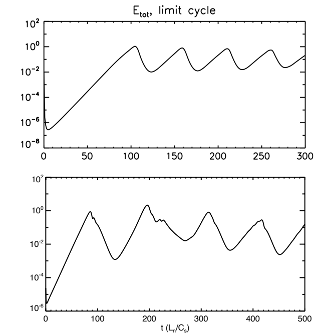


Figure (3): Qualitative comparison of ref [3] time trace (top) of $E_{tot} = 0.5\,(<n^2> + <|\nabla_\perp \phi|^2>)$ with BOUT results (bottom) for limit cycle case (ρ_s=1.0)

Limit Cycle Case Profiles

- In limit cycle case, after initial linear energy growth, system is alternating between strong zonal flow ($m=0$ fluctuations) with with weak finite m modes and strong finite m modes with weak zonal flow (case ρ_s=1.0).
- Predator-pray model of BOUT simulation limit cycle case has been plotted below and shows close behavior to ref [3].

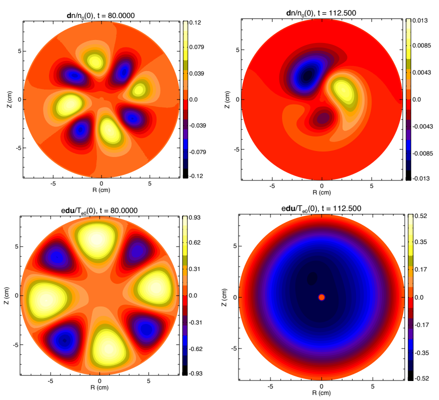
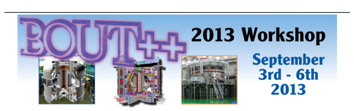


Figure (4): Snapshots of potential and density during linear (left) and non-linear (right) phases of limit cycle case



Simulation Spectra Comparison with Experiments

- Taking cross-power spectrum of density and potential in Fourier space, we can compare experiments spectrum with simulation.
- Qualitatively, spectrums seems to peak at right radial location with about same frequency as experiments, for 2.4kG case this agreement is less obvious though. For complete verification, more case study and perhaps more sophisticated schemes needed.

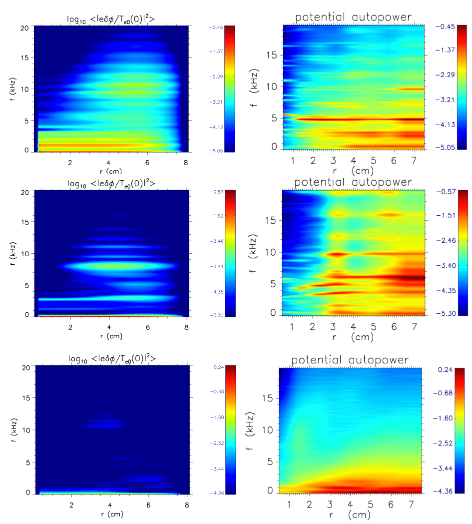


Figure (5): Potential autopower spectra of simulation (left) and experiments (right) [4] for different applied fields: 1kG (top), 1.4kG (middle), 2.4kG (bottom)

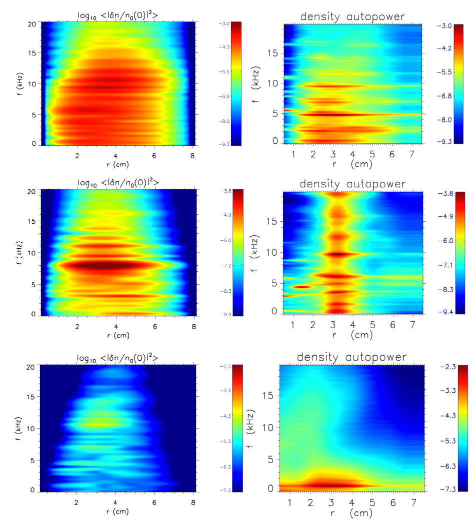


Figure (6): Density autopower spectra of simulation (left) and experiments (right) [4] for different applied fields: 1kG (top), 1.4kG (middle), 2.4kG (bottom)

Conclusion and Future Work

- A simple technique is to compare RMS average of density autopower in Fourier space,

$$\delta n_{RMS} = \sqrt{< \delta n^2\left(r,\theta,t\right) >_{(\theta,t)}}$$

- Given number of similar run for both experiments and simulation, we can plot RMS of autopower density (from 0 to 50kHz) as,

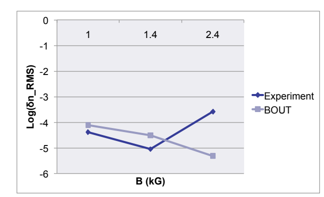


Figure (7): Simulation and experiments trend analysis

- We can observe that around limit cycle case and mid-range B case, simulations and experiments have good agreement. However, for higher magnetic, divergence is contrary to expectation and may indicate to some un-captured physics.
- More detailed study needed to complete verification and understanding of resistive drift-wave instability of CSDX.

References:
[1] Burin et. al., Physics of Plasmas 12 (2005)
[2] B. Dudson, Computer Physics Communications 180 (2009)
[3] C. Holland et. al., Plasma Phys. Control. Fusion 49 (2007)
[4] S. C. Thakur, Transport Task Force Workshop (2013)